The Liming OF SOILS

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LIME applied to soils benefits them in several ways. It neutralizes acids in the soil and stimulates the proper decomposition of organic matter, improves the physical condition of heavy soils, supplies calcium and promotes bacterial activity in the soil, making other elements available to growing plants, and generally increases the efficiency of manures and fertilizers. It facilitates the production of green-manure crops for soil improvement.

The great majority of the soils of the East and South and portions of the central West are deficient in lime, and most of them will respond to liming in increased crop yields. In the following pages information is presented regarding factors to be considered in the practice of liming and the chemical, physical, and biological changes brought about in the soils by liming. The relation of liming to soil fertility, soil improvement, and the efficiency of crop production is discussed. The materials used in liming are described, and information is given as to their comparative effectiveness.

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THE LIMING OF SOILS

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INTRODUCTION

THE BENEFITS of lime to soil and crop are known to most farmers, yet the return of lime to the land in humid regions of the United States almost nowhere keeps pace with the loss of lime through leaching and cropping. Throughout most regions there are abundant deposits of limestone, marl, chalk, or other sources of agricultural lime, often near at hand, and satisfactory methods of testing the soil and preparing and applying the needed amount of lime have had widespread trial, but depletion continues on the vast majority of the farms.

From colonial times it has been a local custom to scatter lime on farms in the vicinity of limekilns. However, liming did not become a widespread practice in the United States until the last years of the nineteenth century, when a period of rapid progress in agricultural science began. By that time the first fertility of new lands in the Midwest had begun to show signs of exhaustion. Farmers became interested in whatever would help to maintain the productivity of their fields. Study and practice have now established a basis of confidence in the use of lime. It remains for the farmer to obtain closer application of established scientific and economic principles to his individual soil problems in order that his crops and his farm may continue to measure up to his reasonable expectations.

[1] Revised under the supervision of Oswald Schreiner, principal biochemist in charge, Division of Soil Fertility Investigations.

The term "agricultural lime," formerly used of burned lime, is now commonly applied to any form of lime intended for use in soil improvement. The term "liming," as used in farming operations, means the application to the soil of limestone—ground, burned, or burned and slaked—or other material containing lime (calcium) as a soil amendment and in form available for plant use.

All plants need calcium to build up their tissues. It has long been considered among the first 10 elements essential to the growth of practically all green plants. All soils contain some of it in the soil minerals, often in the form of carbonate of lime. Soil water, holding carbon dioxide in solution, dissolves this carbonate of lime for ready use by plants; and yet this solubility makes lime rather easily lost by leaching into subsoil or drainage. In dry regions lime accumulates in the soil faster than crops and leaching by the usual rainfall can take it away. But in the moister regions of the United States the reverse is true; the soils lose lime faster than native soil materials can supply it. Most of the soils of the West are lime-accumulating, whereas soils of the Eastern and Southern States and parts of the Central States tend, under cultivation, to become more and more deficient in lime.

As yet the farmers of no single State have come near to using enough lime to keep up the lime balance in their soils. Of the total national consumption of agricultural lime, about three-fourths is credited to the Midwest, where the estimated annual losses in calcium carbonate above what is returned to the soil in manures and crop residues range from 100 to 500 pounds an acre. On cropland in New England and the Middle Atlantic States liming is less general, but more lime is used to the acre than in the Middle West. Comparatively little liming is done in the South, although the loss from the soil by leaching is great because of the heavy rainfall.

Liming alone may make the land productive, or it may be but one of several measures necessary. The most profitable as well as the most striking effects may be seen on soils good in most respects but relatively low in lime.

Lime stimulates the growth of some crops to such an extent as to assist materially in the elimination of weeds. By increasing the yields of legumes, the use of lime may also help farmers in replacing a one-crop economy by a type of farming embracing livestock raising and feeding, or dairying. Not the least valuable result of liming the land is the encouragement it gives to the farmer in his work and management of crop rotations and care of the soil. The limed farm is likely to build up rather than wear out, and the quality of its products tends to perpetuate the interest of the farm family in the land.

Savings are often made by obtaining proper tests of the soil to show how much lime is needed to put it into condition for the crop or crop rotation planned. Quantities required to bring about the desired soil reactions vary greatly with soil and climatic conditions. On some land, lime-loving crops may not be receiving quite enough lime for best returns. It may be, on the other hand, that the lime spread liberally on one field would have been enough for much larger acreages in ordinary crops. Steadily improving service is at the disposal of the farmer in most States and counties to give him adequate information on the liming of his land; and in many counties farm organiza-

tions have arranged for the production, hauling, and efficient spreading of lime in the field at low cost.

With a supply of suitable lime assured, questions of practical use arise. The answers depend upon the needs of the soil, the crops to be grown, the crop rotation, and other factors, such as the spreading machinery to be had, and how much under the existing circumstances should properly be invested in liming.

FARM PRACTICE OF LIMING

The farmer often can increase his crop yields by liming, and by liming in conjunction with the growing of legumes he can increase the fertility of his soil for future crops. Ground limestone and other lime products in carbonate form are not harmful to plants and may be spread at any time, although applying lime, manure, and certain ammonia compounds at the same time is not usually advised. Application of lime after plowing, to be followed by harrowing in, is the most general and satisfactory practice. The time and method used have to be decided in each case according to conditions and the farmer's convenience. The lime should be thoroughly and uniformly distributed through the soil. Burned lime requires more care in application, as it may possibly injure tender plants or seeds if they come in contact with it. Factors of soil, crop, and lime must all be considered in the practice of liming.

THE SOIL

All soils that need lime do not need it for the same reason. As a result of liming, a soil may be benefited through the neutralization of its acidity, the supplying of available calcium when this element is deficient in the soil, or the improvement of its physical condition. In some cases all these effects will be obtained at the same time. In nearly all instances decomposition of the organic matter will be hastened.

The kind of soil and the results to be accomplished will determine in part the practice to be followed. Peats, muck soils, and nearly all soils devoid of carbonate of lime and having poor drainage are likely to be decidedly acid, and the liming of these should be practiced with a view to neutralizing this acidity. A large application of lime may be needed for this purpose.

A heavy soil that has become compacted so that drainage and circulation of air are hindered should be limed to improve its physical condition. For that purpose comparatively small applications will be effective if the soil is not acid. It may be that the topsoil is in fairly good physical condition but the drainage is poor because of the presence of a hardpan or impervious layer below the surface. Surface applications of lime may remedy such conditions very slowly, if at all. In some such cases merely breaking the compacted layer may be sufficient to remedy the condition, but in others, drainage must be provided by ditching or tiling.

Even small applications of lime are likely to stimulate the decomposition of organic matter. This organic matter is of service because it decomposes, but to hasten its decomposition in a sandy soil that contains little organic matter is to rob future crops. For this reason lime in any form should not be applied to soils that are very low in

organic matter, especially in warm, humid climates, without making provision to put organic matter in the form of manure or cover crops into the soil to keep up and if possible increase the supply of this necessary soil constituent.

THE CROP

The kind of crop as well as the nature of the soil will determine whether lime should be added to the soil for best production. Leguminous plants usually require a plentiful supply of calcium; that is, the common legumes take large quantities of calcium from the soil. Further, many legumes are sensitive to acid soil conditions and grow poorly or not at all where such conditions exist. This is particularly true of alfalfa, red clover, sweetclover, and perhaps to a less degree of alsike clover and vetch. Cowpeas and soybeans usually respond to liming but do fairly well on slightly acid soil. White clover also grows comparatively well on acid soils. The pronounced response of alfalfa to liming on an acid soil is illustrated in figure 1. Figure 2 shows the effect of liming on soybeans, and figure 3 on alsike clover.

FIGURE 1.—Effect of liming on growth of alfalfa: *A*, Limed; *B*, not limed.

FIGURE 2.—Effect of liming on growth of soybeans: *a*, Plants from limed field; *b*, same number of plants from unlimed field.

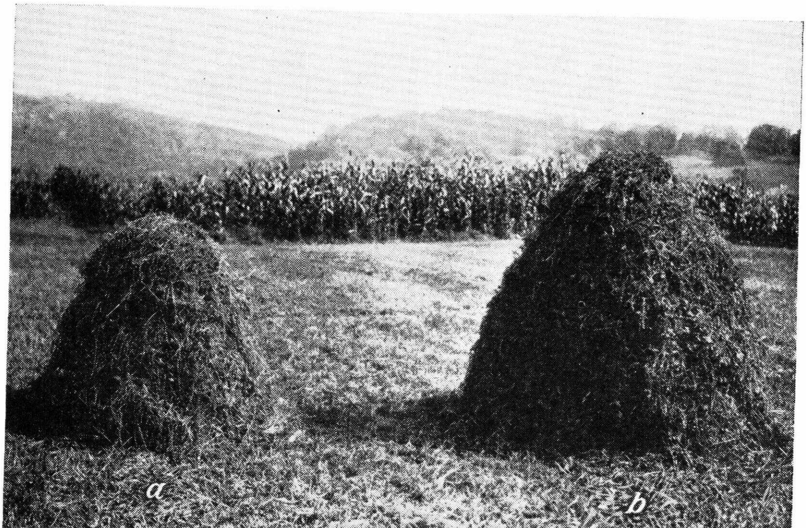

FIGURE 3.—Increased yield of alsike clover caused by liming: *a*, Yield from unlimed plot; *b*, yield from limed plot of the same size.

Corn and cotton are usually considered to be tolerant of acid conditions, and redtop, Bermuda grass, and lespedeza grow well on acid soils. Bog plants, such as blueberries and cranberries, require an acid soil, and such fruits as strawberries and raspberries apparently are not benefited by applications of lime except where the acidity of the soil is excessive.

The great majority of garden and truck crops and cereals usually are benefited by liming; but when it is recognized that different soils may require lime for different reasons, it is clear that a crop that responds to liming on one soil may not do so on another. For this reason it is important that farmers should determine the response of different crops to liming on their own soils. County agents or the soil specialists of the State agricultural experiment stations usually can give sound information on this subject. Beyond this, individual farmers must rely on their own observations.

The application of lime every few years suffices to keep the reaction of most soils favorable for crop production. In the crop rotation, lime should be applied to that crop which benefits most. Such a crop is the clover or other legume grown for market, feed, or soil improvement. Such also are truck crops having the higher calcium demands, such as lettuce, members of the cabbage family, and celery. Applications should not be made to crops in the rotation that grow successfully under acid soil conditions; for example, cotton in the South, and such truck crops as potatoes, strawberries, and melons.

TIME AND METHOD OF APPLYING LIME

The kind of liming material obtainable, the nature of the soil and the crop, the farmer's equipment, and the state of the farm work largely fix the time and method of liming.

Lime may be applied by drilling with a seed drill or by spreading with a lime spreader. A common type of horse-drawn lime spreader is shown in operation in figure 4; tractor-drawn equipment is shown in figure 5; and figure 6 gives a close-up view of a modern lime distributor attached to the truck that brings the lime directly from the bin to the field. Drilling is not a satisfactory method if the lime is not in a proper condition to be uniformly distributed. Various types of lime spreaders are on the market, and it is often possible for the farmer to devise satisfactory home-manufactured machines for this purpose. A manure spreader can also be used in liming by putting a thin layer of manure or trampled straw in the bottom and gaging the load according to the quantity of lime to be spread. Placing burned lime in piles in the field and slaking it by the addition of water or allowing it to slake in the air and then spreading it by hand, as is sometimes done, is a very disagreeable operation, and uniform distribution by this method is hard to accomplish.

QUANTITY OF LIME TO USE

The quantity of lime to be applied depends upon the various needs of the soil, on the form of lime used, the crop, climatic conditions, and the time of application. Applications are usually from one-half ton upward of burned lime or from 1 ton upward of ground limestone per acre, although beneficial results frequently may be ob-

FIGURE 4.—Applying lime with a spreader.

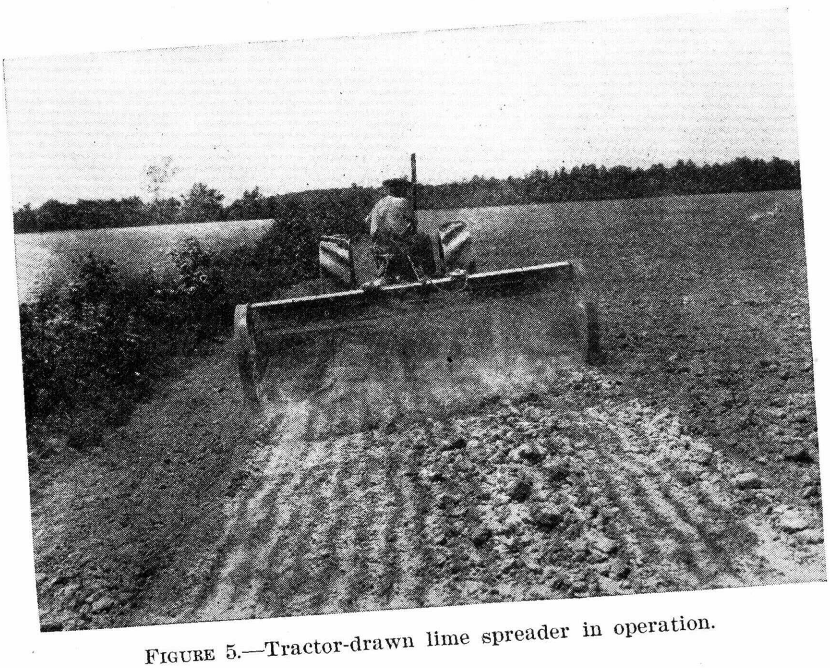

FIGURE 5.—Tractor-drawn lime spreader in operation.

FIGURE 6.—A truck bringing lime directly from the pulverizer to the soil, using one type of distributor.

tained with smaller quantities. Conditions that make it necessary to lime soil tend to recur, depending upon the soil and its treatment; therefore the liming has to be repeated from time to time.

Sometimes the use of a large amount of lime at a single application, or smaller quantities frequently, may bring difficulties, owing to chemical reactions in certain soils causing some of the essential plant foods to become insoluble and unavailable to plants. Plant-food deficiencies caused by overliming are more common in sandy and sandy loam soils than in clays and clay loams.

The question whether a large application once in several years is preferable to smaller applications more frequently is one regarding which no general rule can be made. Arguments can be presented in favor of each procedure, and it is a matter that experiment and experience must decide. The present tendency is toward lighter applications at more frequent intervals.

RELATION OF SOIL TYPES TO NEED AND USE OF LIME

Soils are developed from a great variety of underlying parent materials—from bedrock of various kinds, and alluvial, glacial, wind-laid, and lake deposits. They naturally owe something of their character and composition to the mineralogical and physical characteristics of these materials. In many places, however, forces of the environment, that is, the climate, vegetation, and animal and bacterial life, greatly modify or almost entirely change the nature of the original materials. Rainfall, temperature, and plants and microorganisms at work in the soil cause ceaseless chemical activity. One of the soluble compounds set free by chemical change of the soil minerals is lime, which is largely removed by leaching in some soils but is accumulated in others.

Water moving downward in the soil dissolves and carries with it lime and other salts. It also carries clay and colloidal particles and deposits them in the subsoil. In humid climates and in locations where drainage is good, most of the lime is carried down and out of the soil. On the other hand, trees, shrubs, grasses, and various deep-rooted plants reach down into the subsoil and substrata and bring up some of the lime and other salts and, on decaying, return them to the soil. But in more arid climates the normal rainfall penetrates only a short distance and a layer of lime concentration—in places a cemented hardpan—is formed. Thus the soils are divided broadly into two groups—those in which lime accumulates, and those in which it does not. The "lime line" drawn north and south across the United States, roughly between the prairies and the Great Plains (fig. 7), separates the two groups of soils and in a general way shows where agricultural lime is needed and where it is not. There are, of course, exceptions on both sides of the line. West of it the soils usually, and the subsoils always, are rich in lime, except in some of the higher mountain areas and in those parts of the Pacific Northwest that have heavy rainfall. On the other hand, east of the lime line there are a few southern soils developed on marly material and rich in lime, also other areas farther north where the soils are underlain by calcareous glacial, loessial, or lake deposits or by limestone, that need little or no lime to render them fit for the production of even such lime-loving plants as alfalfa and clover.

Such of the eastern soils as were forest-covered in their natural state have undergone much leaching. In virgin condition, soils of the Prairie group usually had quantities of lime and basic material returned to them by the grasses that covered them for ages. Under cultivation the loss of lime has been accelerated until at least moderate applications are generally needed to improve the structure of the soil and for the best development of such crops as the legumes.

The relative need of additional lime may be judged partly from the soil type. The Houston-Austin-Denton area of the Blackland Prairie in central and eastern Texas has soils developed from marls under a moderate rainfall and tall grass vegetation and as a whole are rich in lime. The soils of the Hagerstown-Frederick areas of the limestone valleys of the Appalachian region are developed from weathered limestone material under abundant rainfall and deciduous forest. The surface soils and subsoils are leached and are more or less acid in reaction, but the underlying limestone furnishes a supply of lime for deep-rooted plants and tends to prevent the development of extreme acidity in the soils. Such soils need some lime for growing alfalfa, clover, and cereals, though the lime requirement is not high. The Norfolk-Ruston soils of the South are developed from sandy materials containing little lime, under high temperatures, heavy rainfall, and intense leaching, and for certain kinds of crops they must receive liberal applications of lime at rather frequent intervals. Many areas contain complex patterns of contrasting soil types, some rich in lime and others poor.

The accompanying map (fig. 7)[2] shows in a general way the lime content of the soils of different geographic areas east of the lime line

[2] This map is based on information from soil surveys and was prepared by J. Kenneth Ableiter, senior soil technologist, Soil Survey Division.

and in the Pacific Northwest. Areas are characterized as having soils of high, medium, and low lime content. No general map showing lime needs can be depended upon for specific lime requirements of any particular farm or field.

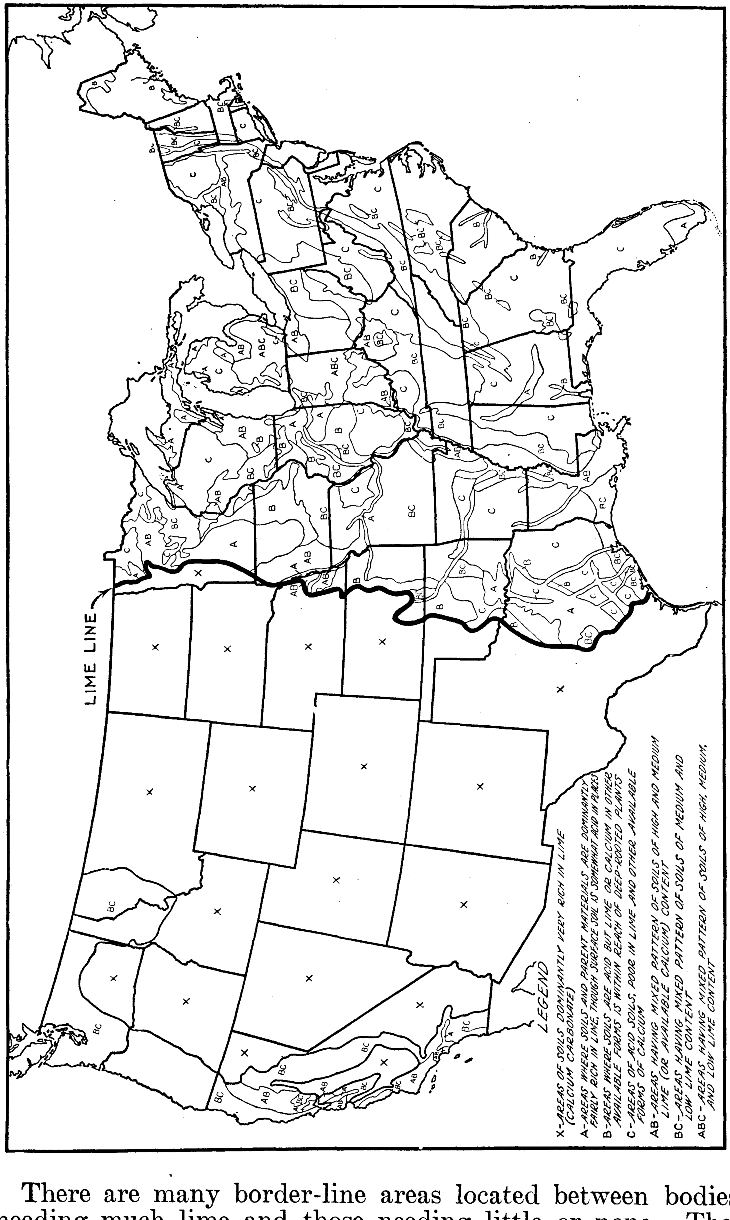

FIGURE 7.—Relative lime content and acidity of soils of the United States. Areas characterized as having soils of high, medium, and low lime content usually need the application, respectively, of very small, moderate, and comparatively large quantities of lime. Note the "lime line" roughly dividing the lime-accumulating soils from those likely to be deficient in lime.

There are many border-line areas located between bodies of soil needing much lime and those needing little or none. The general level of productivity in many transition areas can be improved by thorough examination of the soils and application of proper amounts

of lime. Some of these soils, although poor in lime and none too rich in plant foods generally, are adapted under good farming practice to the development and maintenance of a stable agricultural community life.

NEED FOR LIME IN CONJUNCTION WITH ACID-FORMING FERTILIZERS

A need for liming soils has developed in recent years where large quantities of acid-forming fertilizers are used. Soil acidity caused by acid-forming fertilizers may be controlled by the annual application of small quantities of lime. If acid-forming fertilizers—that is, those containing ammonia or acid-forming synthetic compounds—are used, dolomitic limestone may be included in the fertilizers in sufficient quantity to neutralize the acidity that may develop in the soil. The need for liming in conjunction with the use of acid-forming fertilizer is greatest in sandy and sandy loam soils and in heavy fertilizer-using sections.

MAGNESIA ALSO REQUIRED

Dolomitic limestone gives the soil magnesia, also needed by growing plants and animals. Like lime, magnesia compounds carry along with them supplies of potash and phosphorus from the soil to the plant. Chlorosis of the leaves is an unthrifty condition resulting sometimes from a deficiency of magnesia. Application of limestone containing magnesia to the soil is usually beneficial, and soils rich in magnesia may be very fertile. Should there be an excess of this element, lime is usually added as a corrective.

Tobacco on sandy soils, berries, and sometimes potatoes may require treatment with dolomitic limestone. Corn, small grains, and beets use important amounts of magnesium carbonate. Fruit and nut trees, soybeans, cotton, flax—in general, plants with oily seeds—require it. A single application of dolomitic limestone may be sufficient to last for many years.

EFFECTS OF LIMING

Of the several effects of liming, the correction of soil acidity is probably the most commonly thought of and spoken of. This, however, may not be the most important effect. It is evident that several or all of the effects of liming may operate in the same soil at the same time, and it is likely that in very few soils the benefits resulting from liming are the result of one action only.

CORRECTING SOIL ACIDITY

Many soils contain compounds of an acid nature, derived from complex silicates that form a large part of the rocks from which the soils are formed. These compounds use up lime in much the same way that ordinary acids do; that is, they require the addition of lime before a neutral condition or an alkaline reaction can be brought about.

Another source of acidity is the decay of organic matter in the soil. Any of these acid compounds may combine with the mineral constit-

uents of the soil, their acid natures being thereby neutralized; or they may be prevented from accumulating to an injurious extent by drainage or by changes promoted by free access of air. When such neutralization or change does not take place and acids accumulate, the soil becomes acid, or sour. This condition can be corrected by the application of lime, which serves to "sweeten" the soil.

Caution is needed, however, where lime is applied in connection with manuring or with the plowing under of green crops. If the manure or the crop is rich in ash it usually is rich also in lime. Sometimes barnyard manure, instead of increasing the acid in the soil, may remain neutral during decomposition, or it may even become alkaline. Alfalfa has a similar tendency to remain alkaline, whereas straw and many leafy crops in decomposition may be moderately to strongly acid.

These facts should be taken into consideration in computing the amount of lime to be applied per acre and the time and method of spreading. Recognizing possible losses arising from combinations of manure and commercial fertilizer constituents to form additional acids, soil chemists are giving more attention recently to compounding fertilizers that will have the most favorable reaction effect for particular soils and conditions.

Burned lime and ground limestone both have the power to neutralize acids. Burned lime combines directly with the acid, thereby forming a neutral compound; and limestone enters into a reaction with the acid, whereby carbonic acid gas is liberated and the same neutral compound formed.

STIMULATING THE DECOMPOSITION OF ORGANIC MATTER BY MICRO-ORGANISMS

All soils contain some organic matter, derived from the remains of plants, previous crops, or similar materials that have been added to the soil. This organic matter decays in the soil through the activity of micro-organisms, which is accompanied by the production of acids. Unless sufficient lime or other bases are present to neutralize these acids, decomposition is slowed down or even stopped. Micro-organisms need a certain amount of lime and are affected more or less by soil acidity. Liming, therefore, makes conditions more favorable for their growth and increases the rate of decomposition of organic matter by the micro-organisms that use it as a source of energy. In certain special cases, as with mucks and peats, liming does not hasten the decomposition greatly, owing to the resistant nature of the organic material.

One of the advantages of an adequate supply of organic matter in the soil or of supplying it by means of manure, fertilizers, or cover crops, is that in the process of decomposition of this material, nitrogen and other nutrients are released and are then available for crop growth. Lime not only stimulates decomposition but makes its products beneficial to growing crops. A soil markedly deficient in organic matter or containing organic matter but little of which can be decomposed is worth little for general crop production. However, some soils of a sandy nature bordering on the Atlantic seaboard, although almost devoid of organic matter, are valuable for the production of rapidly growing truck crops. Such soils must be supplied periodi-

cally with large quantities of commercial fertilizer and must be limed occasionally for the successful production of crops.

SUPPLYING NEEDED CALCIUM TO PLANTS AND ANIMALS

The assumption is general that soils contain sufficient calcium to satisfy the needs of a plant in building up its tissues. This, however, may not always be the case. One of the beneficial results of liming may be the direct supplying of needed calcium to the plant. There are soils in which the content of lime in any form is less than the content of any other common element. In growing on these soils crops such as clover (fig. 3) or alfalfa (fig. 1), which require large quantities of calcium, the benefits of liming may therefore be due, in part at least, to the direct supply of calcium.

Roughly, 1½ percent of the weight of live animals has been found to consist of lime, which is necessary in the formation of the bones, teeth, and cell walls, as well as in the production of the blood and the milk. It is a familiar fact that the shell of an egg is almost pure lime. It is largely through the calcium content of pasture grasses and forage crops, and to a less extent of grain, that animals derive the needed lime to form bones and other tissues without which healthy stock is impossible. Milk also contains appreciable quantities of calcium and is one of the most important sources of this element in human nutrition. Without an adequate supply of lime in some suitable form in the diet of animals or man, serious diseases result.

IMPROVING THE PHYSICAL CONDITION OF HEAVY, COMPACTED SOILS

In heavy soils that contain large proportions of clay or silt, under certain conditions, the fine soil particles become associated so closely that free access of air and water is prevented, a condition unfavorable to plant growth. Under other conditions the fine particles tend to gather in small groups or floccules, each group behaving as a large particle. The soil particles are then said to have flocculated, and the soil has a crumb structure. Farmers know this crumbly condition of the soil when they see it, and they know that in tilling soils it is desirable to bring about this condition.

Liming has been found to favor the flocculation of heavy soils, so that the better aeration and drainage that result from the liming of heavy, compacted soils are among the important effects of liming. Burned lime and hydrated lime are more effective than ground limestone in bringing this about.

INCREASING THE AVAILABILITY OF OTHER MINERALS IN THE SOIL

One of the beneficial results from liming is the effect of lime in rendering other minerals—such as those containing potash—soluble and available to the growing crop. This effect, though it may be somewhat general, is not the same for all soils, and in some soils it is even negative. Whether or not the chemical action of lime upon other minerals is extensive, improvement of tilth of the soil and stimulation of plant growth result in more root penetration of the soil and more contact with minerals in forms available for plant food.

An unbalanced soil shows marked effects on the health and growth of crops. Either highly acid or highly alkaline conditions may cause a deflocculation of the finer colloid particles in the soil, permitting them to leach into the subsoil, sometimes forming a hardpanlike layer detrimental to crops. The correct amount of lime in the soil will prevent this. An acid soil locks up much of the valuable phosphorus, and lime itself becomes less available to plants because it is taken up in chemical reaction with the acids. On the other hand, iron, zinc, manganese, and copper are less available if the soil reaction is alkaline, which may be a reason why unfavorable results are sometimes encountered where sandy land low in organic matter is limed.

Individual crops respond differently to soil conditions. Alfalfa, taking much nitrogen from the air, draws heavily upon the bases in the soil, and the soil must have lime to prevent it from becoming too acid. Potatoes thrive in comparatively acid soils; if the soil is too near neutral, potato scab appears. Sulfur or some other acid-forming chemical is then added to the soil to control the disease.

INCREASING THE EFFICIENCY OF MANURES AND FERTILIZERS

Maximum returns from stable manure, green-manure crops, and commercial fertilizers may not be obtained where adverse soil conditions, such as poor drainage, poor tilth, or high soil acidity, exist. Application of lime to many acid soils long under cultivation, as well as to forest soils newly cleared for cultivation, should precede the use of manures and fertilizers. Applying lime will result in larger returns and lower production costs for many crops.

SOIL IMPROVEMENT BY MEANS OF LIME AND GREEN MANURE

The practice of liming is very closely related to that of growing green crops to be plowed under to furnish organic material to the soil. Good results frequently follow the plowing under of green crops where no liming is practiced, but usually the benefit would be greater if lime were applied to the soil.

Turning under the vegetation of leguminous crops for green manure is one of the principal means of soil conservation and improvement of the fertility of land. Most of the soil-conserving and soil-improving crops adapted to large areas over the country grow best and produce most vegetation when the soil is kept nearly neutral in reaction by liming. Soil-building crops, including most of the legumes and the grasses, are benefited by liming. Many of the clovers cannot be grown successfully on some soils without first applying lime. Lime, disked in, usually increases the carrying capacity of pastures.

When the growth of soil-building crops is increased, larger residues of vegetable matter are left in the soil, and as a result of their decomposition, plant food is released for the crops that follow. Liming after green-manure crops have been plowed under is considered good practice; however, on some heavy acid soils it has been observed that young green-manure crops reduced soil acidity soon after they were turned under but that subsequently the soil acidity again increased. On sandy soils in the South, where summers are long and the temperature comparatively high, liming soils where green-manure crops

have been turned under may cause too rapid decomposition of the vegetable matter and a loss of fertility through leaching before the liberated plant food can be used by the crop following.

Very few farms produce sufficient barnyard manure to maintain the organic content of all the farm land and the farmer may resort to the growing and plowing under of green-manure crops. To lime the soil before planting usually means a great increase in the amount of green vegetation to incorporate in the soil.

SOIL ACIDITY AND LIME REQUIREMENT

Soil conditions that make liming desirable or necessary are in many cases recognized through simple observation. Since these conditions are so generally associated with soil acidity, however, the need for lime and the quantity to be applied are usually best determined by finding out whether the soil is acid and how acid it is.

INDICATIONS OF SOIL ACIDITY

If the soil has poor drainage, or if it is peat or muck not intimately associated with marl deposits, it is usually acid. Most forest soils and many soils underlain with rock other than limestone are acid to greater or less extent. Soils depleted by cultivation and eroded by water generally give an acid reaction.

The character of native vegetation may indicate an acid soil. Cone-bearing trees, chestnut, sassafras, scrubby oak growths, and jack pine usually are acid-soil indicators; so are wintergreen, blueberries, mosses, horsetail rush, and such weeds as sorrel and spurry. Acid-tolerant plants, however, may thrive on sweet soils as well. On the whole, cultivated soils that may be slightly acid do not indicate the fact in any way that is conclusive to the farmer. Although it is useful to know the natural indicators of the general condition of the soil, the actual degree of acidity and the quantity of lime needed can be determined only by chemical methods.

TESTS FOR SOIL ACIDITY

The usual tests involve chemical and color changes. One of them is the old litmus-paper test. A strip of blue litmus paper is brought into contact with moist soil; if the paper turns red, the soil is acid. If the soil changes red litmus paper to blue, it is neutral or alkaline. But the degree of acidity is hard to judge in this way. In the colorimetric tests now in use, soils or soil solutions are treated with chemical indicators and the resultant colors checked against color charts, showing with greater accuracy the degree of acidity or alkalinity of the soil. There are also quantitative and electrochemical tests. Methods of sufficient accuracy are used and tests are made free or at nominal cost to the farmer by State agricultural colleges and other agencies.

Because many farms and fields have a great variety of soils, it is usually recommended in sampling to take a topsoil sample from the first 6 inches of depth from every acre. One or several subsurface samples and a subsoil sample are taken from each field. The subsoil sample should ordinarily come from a depth of 4 feet. When the soil-acidity tests are completed it is a good plan to make a map of

the fields, showing where lime is needed and how much is needed to the acre. Complete instructions on taking the samples can be had from the agency making the tests.

The degree of soil acidity can be accurately measured. The "pH value" has become the usual expression for the degree of acidity or alkalinity as shown by a scale with 7 standing for the dividing line or neutral point between acidity and alkalinity. The values below 7, that is, a pH of 6, 5, 4, etc., denote increasing acidity; whereas values above 7, that is, a pH of 8, 9, or higher, denote increasing alkalinity. If it be said, for instance, that alfalfa thrives in a soil with a pH of 7 or 7.5, wheat with a pH of 6, and timothy with a pH of 5, it means that alfalfa produces well on a neutral or a slightly alkaline soil, wheat on a mildly acid to neutral soil, and that timothy is more tolerant of soil acidity than are the other two crops.

Because these small numbers are used with pH to express the degree of acidity, one is likely to conclude hastily that there is slight difference in acidity. The contrary may be the case, because the figures of the scale are logarithmic and denote only a tenth of the actual variation. For instance, a pH of 6 is only one-tenth as acid as a pH of 5, and only one one-hundredth as acid as a pH of 4. Sometimes, though rarely, a soil is found too acid to repay any attempt to neutralize it.

The pH value of a soil may be determined by electrical or by color methods. The electrical methods are the more accurate but require expensive and complicated apparatus, and their use is confined for the most part to the laboratories. The color methods make use of dyes, referred to as indicators, which show color changes depending on the degree of acidity or alkalinity of the soil tested (that is, the pH value) when placed in contact with the soil. By comparing the exposed indicator with a standardized color chart the pH value is directly determined. Of the numerous colorimetric methods available, many are relatively simple in operation and may be carried out in the field, giving results sufficiently accurate for many practical purposes. Correct interpretation of results of even the simpler tests, however, requires some experience and a knowledge of the soil type as well as of its cultural history. The county agent usually has at his disposal facilities for measuring the pH value of soils, at least by the simpler methods. Wherever possible, the county agent or a State experiment station worker should be consulted in making such tests.

LIME REQUIREMENT

The term "lime requirement" is frequently used in discussing the liming of soils. It usually means the quantity of lime that must be added to a soil to bring about a slight alkaline reaction. Such lime requirement includes not only the lime necessary to neutralize any acid present but also that which may be used up by the soil in other ways, such as absorption by very finely divided soil material (colloids) or by chemical reaction with soil materials. This lime requirement is usually stated in pounds of oxide or carbonate of lime required for an acre of soil to a depth of 6 inches. It is most accurately determined by methods that require laboratory equipment and are not adapted for field use.

Whereas both mineral and organic acids contribute to soil acidity, the soluble acids are less responsible than the insoluble soil colloids for the "absorption" of lime. When the soil is "sour," the exceedingly small colloid particles cling tightly to the surface of the larger soil particles. But when the soil is limed adequately, the fine colloid particles, which have been called the exchange and storage material of the soil, become saturated with lime and give up their hold upon other particles, with a resultant granulation of the whole soil mass into a satisfactory crumblike structure. To correct soil acidity, therefore, sufficient lime is needed to saturate and reload the fine soil-exchange material with bases, as well as enough lime to neutralize the soluble acids.

The pH value is not directly a measure of the quantity of lime needed but is rather an indicator of the degree of acidity; and in practice, many soils that do not show a strongly acid pH value nevertheless require the application of a considerable quantity of lime to change their reaction. However, for soils of similar type, fairly good correlations between pH value and lime requirement have been obtained, and in the hands of experienced workers the pH value in such instances should be a useful index to the lime requirement.

LIMING MATERIALS

LIME AND ITS FORMS

Lime, or calcium, is one of the principal elements in nature. It can be isolated as a silver-white metal, although it never appears native, but in combination with other elements. Its most commonly known compound is carbonate of lime, which is common limestone. Bicarbonate of lime is a form found in "hard" water. Oxide of lime is best known as quicklime or builder's lime. Some of the compounds of lime are essential to plant and animal growth; and as found in the soil or applied to it, lime is indispensable to agriculture.

The same weathering process that leaches lime out of the soil deposits it in the subsoil or carries it off in the streams into lakes, or seas, or caves. Most marl originated in this manner, the precipitated lime material, usually with some sand or silt, remaining in a lake bed, granulated and unconsolidated. The limestone beds usually are older, composed largely of ancient sedimentary marine deposits of fossilized shells, coral, or the skeletons of minute animals, all containing lime and cemented by chemical forms of lime into solid rock. Chalk is the product of very finely divided fossilized shell particles. Marble is metamorphosed limestone, usually very pure, crystallized by pressure or heat. There are other forms, such as tufa and the stalactites in caves, the result of deposition of lime by springs or dripping water. As might be expected from their origin, limestones vary greatly in percentages of lime and in the occurrence of usable bodies of material.

The Association of Official Agricultural Chemists has adopted officially an interpretation of the word "lime" as applied to fertilizer, as follows:

> The term "lime" shall not be used in the registration, labeling, or guaranteeing of fertilizers or fertilizer materials, unless the lime is in a form to neutralize soil acidity, such as the oxide, hydroxide, or carbonate, or equivalent magnesia compounds.

Limestone, a lime carbonate compound, is burned to drive off the carbon dioxide, leaving oxide of lime in greater or less purity. By combining water with burned lime it is said to be slaked, becoming hydroxide of lime, or hydrated lime. When further slaked by contact with the carbon dioxide of the air or the moisture of the soil, the oxide and the hydrate forms slowly turn to carbonate, remaining available for plant use over a long period.

LOCATIONS OF USABLE DEPOSITS

Good limestone is fairly abundant in three great belts crossing the United States from north to south. One of these, rather narrow, traces the backbone of the Appalachians, occupying many valley and mountain areas from Lake Champlain almost to the Gulf of Mexico. A wider belt spans the Ohio Valley from Alabama to Lake Erie; and a broad, irregular belt occupies the central part of the Mississippi Valley. With the exception of magnesian limestones near the Great Lakes, in the Ozarks, and western New England, most of the deposits are high-calcium limestone. Both kinds, where found in proper concentration and easy of access, are suitable for making agricultural lime.

Marl is available in numerous localities in the Lake States. Texas has a plentiful supply of chalk and limestone. Shell, marl, and soft-limestone deposits are extensive near the Atlantic and Gulf coasts. Scattered local deposits of hard limestone are found in most of the States from Maine to Florida and also outside the principal lime belts in most other States.

State mining bureaus, extension officials, and State agricultural colleges, experiment stations, and departments of agriculture are able to give additional information on the kind and location of lime deposits. Many local deposits are quite as good as those found in sections favored with more lime. In order to avoid costly mistakes through attempts to develop minerals of unknown purity, the quality of the rock should be tested and borings made to ascertain the depth of the overlay as well as the thickness of the lime-bearing strata. The production of burned lime should be attempted only where there is abundant fuel. State and county bureaus can advise on these and other factors contributing to the cost of lime.

FARMER HAS CHOICE OF MATERIALS

The material used in liming is either carbonate of lime, oxide of lime, or hydrated lime, and there are several forms of each of these. It sometimes happens that because of local conditions a farmer is limited to one form of lime, but usually he has a choice of several kinds or brands. Limestone, marble, marl, shells, and chalk are composed chiefly of carbonate of lime. The burned product of these materials is commonly referred to as oxide of lime, and the water-slaked oxide as hydrated lime. Carbonate of magnesium associated with carbonate of lime in magnesian or dolomitic limestone and the mixed oxides resulting from burning this stone are also included under the term "lime."

The three terms "carbonate of lime," "oxide of lime," and "hydrated lime" are not accurate in a strictly chemical sense, but they are so generally used by dealers and farmers that it has been thought

desirable to use them in this bulletin in place of the more technical names of calcium carbonate, calcium oxide, and calcium hydroxide.

LIMESTONE, OR CARBONATE OF LIME

Limestone is not appreciably soluble in water, but soil moisture holding carbonic acid gas in solution dissolves considerable quantities. It is because of this solubility that lime is gradually leached from the soil. Yet the beneficial effects of carbonate of lime in neutralizing soil acidity, stimulating the decomposition of organic matter, making conditions more favorable for the circulation of air and water by flocculating the soil particles, and making soluble other minerals for plant use, all depend upon the lime's being in solution in the soil moisture. It follows that the value of limestone or other carbonate of lime materials, so far as their chemical activity in the soil is concerned, depends both on their content of carbonate and their solubility.

The rate of solution of one kind of carbonate of lime may be assumed to be the same as that of any other kind having the same degree of fineness. Fineness of grinding also makes it possible for the liming material to be more thoroughly distributed throughout the soil in a shorter time. The value of limestone, therefore, so far as its immediate activity is concerned, depends on how finely it is pulverized.

MAGNESIAN OR DOLOMITIC LIMESTONE

The term "magnesian" or "dolomitic" is applied to limestone that contains carbonates of both calcium and magnesium, the magnesium usually constituting only a small percentage of the total. The general opinion now seems to be that magnesian lime is approximately equal in value to the lime from ordinary limestone, if of the same purity and degree of fineness. For practical purposes the value of magnesian limestone can be judged by its content of the two carbonates and the value of lump lime made from it by its content of the two oxides.

LIME AS OXIDE OF LIME AND HYDRATED LIME

It has been pointed out that any form of lime carbonate furnishes lime oxide on burning. When oxide of lime is brought into contact with water, chemical action takes place, heat is generated, and the lump of lime falls to a dry powder or forms a semifluid milky mass, according to the quantity of water used.

In this reaction (slaking), chemical combination between the oxide and water takes place. Air-slaking also, if long continued, may result in the formation of carbonate, by the absorption of carbon dioxide from the air. The oxide of lime after slaking is known as hydrated lime; and usually when lump lime, or oxide of lime, is used in agriculture, it is slaked and changed to the hydrated form before it is used.

Hydrated lime is much more soluble than carbonate of lime. When it is applied to a moist soil, solution takes place, and this lime in solution tends to be diffused throughout the soil. At the same time it may be converted into carbonate of lime through interaction with the carbonic acid also held in solution in the soil. The extent to which this reaction goes depends on the proportions of the two reac-

tion compounds present. If much carbonate were formed in this way, it would be thrown out of solution and finally react in the soil in the same way as finely divided limestone added to the soil directly.

In some cases, no doubt, there is direct union of hydrated lime with organic compounds without the previous formation of carbonate; but in a general way, the chemical processes by which beneficial effects on crops are produced are the same whether the oxide or the carbonate is used.

If the oxide is applied to the soil without first being slaked, contact with the moist soil will cause the material to slake. It is in this process that considerable heat is generated, and chemical changes may be brought about in the soil at the points where the slaking takes place that are very different from those that result from the application of slaked lime. It is principally the generation of heat and the abstraction of water that accompany slaking which give rise to the popular idea that quicklime produces a caustic or burning effect. As a matter of fact, after slaking has taken place and the normal temperature is reached, the resulting hydrated lime is very mild in its action on organic material.

RELATIVE EFFECTIVENESS OF LIMESTONE, OXIDE OF LIME, AND HYDRATED LIME

In the choice of material the farmer has the following facts to consider regarding the efficiency of lime in the soil: All forms of ground or pulverized carbonate of lime are approximately alike if their purity is the same and they are ground equally fine. It is evident, then, that for immediate effect the value of carbonate as compared with oxide depends on the equivalent value of carbonate when calculated to oxide, and how nearly its fineness approaches the relatively extreme fineness of slaked lime.

The relative value of lime carbonate and oxide of lime is in the ratio of 56 to 100. In other words, 100 pounds of carbonate will, on burning, produce 56 pounds of oxide. It may safely be assumed, therefore, that in the case of ground or pulverized limestone it is only the material of certain fineness that is immediately available and is comparable in value with the fine material obtained on slaking burned lime. Coarse material, however, though not quickly available, is of considerable value, as its slow solubility makes it a reserve store of lime in the soil.

Hydrated lime carries with it the water that has combined with the oxide, and consequently its oxide value for equal weight is less than that of quicklime. The relation between the two is such that 100 pounds of hydrated lime contains approximately 75 pounds of oxide. The relation between the three principal forms of agricultural lime, then, is as follows: 100 pounds of carbonate of lime (limestone) is equal to 74 pounds of hydrate (slaked lime) or 56 pounds of oxide (unslaked burned lime). To put it in general terms, 2 parts of oxide are equal to 3 of hydrate or 4 of carbonate.

FINENESS OF GRINDING AND STANDARDS FOR GROUND PRODUCTS

Specifications regarding the fineness of grinding of limestone have varied considerably. A material a large percentage of which passes through a 60-mesh sieve probably comes near striking the medium

between very fine material at very high cost and coarse material procured cheaply. However, when it is specified that all the material shall pass a 10-mesh sieve, there is usually enough fine material present to produce immediate effects. Cases have been known where limestone was ground so that all the material passed a 10-mesh sieve, and then the fine material was sifted out for other uses. Such slightly pulverized limestone would, of course, be only slowly effective. A considerable proportion of fine material is necessary for immediate effect.

STANDARDS FOR GROUND PRODUCTS

Certain standards of quality have developed in the grinding and use of lime for agricultural purposes. High-calcium limestone for pulverizing should usually contain 90 percent or more of carbonate of lime. Pulverized limestone (fine-ground limestone) should be ground fine enough for all material to pass a 20-mesh sieve, and at least 75 percent of it to pass a 100-mesh sieve. Coarse-ground limestone should all pass a 10-mesh sieve and at least 50 percent of it a 100-mesh sieve. Some material is used that does not come up to these specifications, but its action in the soil is slower. The user is entitled to know both the fineness and the purity of the material.

Shell material should be ground rather fine and should carry the name of the mollusk from which it is made. Waste lime in the form of industrial byproducts from paper mills, tanneries, beet-sugar mills, blast furnaces, acetylene plants, and other sources should be tested carefully to ascertain their value for agricultural purposes. Wood ashes contain more or less lime and potash, especially if they have not been leached too much. Gypsum, or calcium sulfate, sometimes called land plaster, is used for improving the physical condition of certain soils, but it does not neutralize acidity.

The finer the limestone is ground the more it will cost and the more soluble and immediately effective it will be in the soil. There is, however, a point beyond which added expense for fine grinding is not warranted, because the increased crop production does not offset the increased cost of material.

Certain facts should be borne in mind in this connection. It requires approximately twice as much carbonate of lime as oxide or burned lime to bring about the same chemical effect, and it is necessary to have a considerable part of the ground or pulverized limestone fine enough to make it immediately effective. If a quantity of ground limestone contains a fairly large percentage of fine material and tests 85 percent or more of carbonate, 1 ton of it is approximately equal to half a ton of burned lime.

Comparative tests of burned lime and ground limestone have been made on a variety of crops at many of the agricultural experiment stations; and although in some cases burned lime and in others ground limestone has been found to give the greater yield, the general opinion is that superiority of one form of lime over another for increasing crop yield is mainly a question of purity and fineness.

AVAILABILITY OF LIME FOR THE SOIL SOLUTION

Availability as applied to limestone means the ability to become soluble and to become part of the soil solution to react with the soil

or feed the plant. It does not depend entirely upon the condition of the limestone. The soil, the amount and distribution of rainfall, and the temperature are all factors in the effectiveness of liming. This consideration emphasizes the desirability of the farmer's ascertaining what kind and quantities of lime are best suited to the needs of his soil. Such information may be obtained from agricultural agencies or through small-scale experiments that the farmer may conduct in his own fields.

LOSS BY LEACHING

The leaching of lime from the soil, resulting in the loss of valuable material, is a matter that should receive consideration in the practice of liming. It must be remembered that the finer a lime material is pulverized the more quickly it reacts in the soil; and if very fine material is applied in excess, it will be leached from the soil and lost.

This loss by leaching is a factor operating particularly in light soils that have little organic matter and in which the drainage is good or even excessive. It is especially important in the South, where such soils predominate and where the mild climate and heavy rainfall bring about leaching throughout the year.

COSTS

High cost is often blamed as the chief deterrent to liming. Ordered occasionally by a farmer here and there, agricultural lime is likely to be considered by industry as a byproduct and a side line, a condition that does not tend to bring down its cost. Where liming of soils becomes the rule and liming material is ordered regularly in considerable quantity, farmers may be able to obtain price advantages.

About 5½ million short tons of lime were produced and sold for agricultural purposes by industries in the United States in 1936–37.[3] This was an increase of about 21 percent over the preceding year. The value ranged from $1.29 a ton for ground limestone to $7.43 for hydrated lime. Calcareous marl was valued on an average at $1.28 a ton.

Truck and specialty farms use a great deal of sacked hydrated lime, especially where farmers lack equipment to handle agricultural lime in bulk. Sacking and retail carrying charges average about $1.50 a ton. Except where quick action is required, as in the growing of certain specialty crops, ground limestone meets the farmer's needs.

Long freight hauls add greatly to the cost of limestone. Fortunately, lime deposits in some form are found in every State, and the majority of farmers can avoid transportation for excessive distances. Groups of farmers can sometimes interest local quarries in supplying a steady output of agricultural lime at reduced costs. Many county groups make substantial savings by operating their own grinding plants, marl pits, or limekilns. It is preferable to operate these plants at slack seasons and necessary to operate them efficiently. The farmers may do their own hauling and spreading, or they may make savings by having the lime trucked to the farm and spread on the fields directly from the truck by means of an attached spreader. Methods of construction and operation of farm plants are given in Farmers'

[3] U. S. Geological Survey Minerals Yearbook, 1938.

Bulletin No. 1801, Making Lime on the Farm, issued by the United States Department of Agriculture.

As a result of the installation of plants in some counties in 1937 and 1938, farmers within a 6-mile radius of the quarries have been able to get limestone ground, hauled, and spread on their fields for as little as $1.35 to $1.65 a ton. Consequently many farmers used lime who had never used it before. In one State cheaper liming made available to the farmers increased consumption fivefold immediately. Another State, to encourage the use of lime, maintains two lime-grinding plants, making shipments of about 100,000 tons a year. Freight charges on the average cost its farmers more than the material, but the State has had freight rates reduced on lime for treatment of acid soil. Officials of the State report that where lime has once been used the demand for it increases.

One way for the farmer to answer the question whether liming his land will pay is to budget the cost in cash outlay and in labor and time spent in hauling and spreading lime against the probable increase in crop returns, much as he might weigh the outlay against the advantages expected from building a barn or buying a team or a milk separator.

WHAT SHOULD NOT BE EXPECTED OF LIMING

Liming will not take the place of drainage. Acid soil conditions may be due to poor drainage, but lime can improve only the conditions in the upper soil, making for better circulation of air and water. Impervious layers of hardpan are not materially affected by applications of lime; they should be broken up by other means.

Liming cannot take the place of proper crop rotation, cultivation, or soil management. In fact, the use of lime makes it more necessary that rotation and all cultural methods be studied more carefully.

Lime does not supply potash, phosphoric acid, or ammonia, furnished by fertilizers.

Best results should not be expected from an application of lime on soil deficient in organic matter, and liming should not be expected to build up such a soil unless such organic matter is supplied either in manure or by green crops plowed in. On soils deficient in organic matter it is often necessary to lime first, in order to build up organic matter by means of green-manuring crops.

TERMS USED IN LIMING

Acid-forming fertilizer.—A fertilizer that is capable of increasing the residual acidity of the soil.

Agricultural lime and liming material.—The term "agricultural lime" was originally applied to burned lime prepared for agricultural use, but now it is somewhat commonly applied to any form of lime intended for use in soil improvement that contains calcium and magnesium in condition and quantity suitable for neutralizing soil acidity.

Air-slaked lime.—A product composed of variant proportions of the oxide, hydroxide, and carbonate of calcium, or of calcium and magnesium, derived from exposure of quicklime.

Calcareous material.—Material containing lime.

Calcium.—Lime. One of the elements; it never appears native, but in combination with other elements.

Calcium carbonate.—(See Carbonate of lime.)

Calcium hydroxide.—Calcium hydroxide, or hydroxide of lime, is the chemical combination of calcium oxide, or burned lime, and water.

Calcium oxide.—(See Oxide of lime.)

Carbonate of lime.—Carbonate of lime (calcium carbonate) is a compound consisting of lime oxide combined with carbonic acid gas. It occurs naturally as limestone, marble, marl, oystershell, and coral.

Chalk.—A very pure form of carbonate of lime that has been deposited naturally in much the same way as marl.

Colorimetric test.—A colorimetric test is one in which the chemical reaction is measured by comparing the color of exposed "indicator material" to the colors of a standard chart. Such a test is commonly used to indicate the degree of acidity of soil and the quantity of lime the soil needs.

Coral.—The skeleton remains of marine organisms, consisting chiefly of carbonate of lime.

Green manure.—A term applied to any crop grown for the purpose of being plowed under to replenish the supply of soil organic matter. Leguminous crops, such as the clovers and cowpeas, are grown most frequently for this purpose, but others, such as rye, are sometimes used.

Ground limestone.—Ground limestone (coarse-ground limestone) is the product obtained by grinding either high-calcium or dolomitic limestone so that all the material will pass a 10-mesh sieve and at least 50 percent will pass a 100-mesh sieve.

Ground shell marl.—The product obtained by grinding natural deposits of shell marl so that at least 75 percent will pass a 100-mesh sieve.

Ground shells.—The product of grinding the shells of mollusks so that not less than 50 percent will pass a 100-mesh sieve. It should carry the name of the mollusk from which it is made.

High-calcium limestone.—Limestone in which 90 percent or more of the total carbonates of lime or magnesia occurs as a carbonate of lime.

Humus.—A term applied to the more or less dark-colored, thoroughly decomposed organic material in the soil. Humus is known to be made up of a great variety of organic compounds.

Hydrated lime.—A trade name for slaked lime, or hydroxide of lime, manufactured by treating quicklime with sufficient water to combine with the oxides.

Lime.—A term usually meaning calcium oxide. As defined by the Association of Official Agricultural Chemists, the word "lime," when applied to liming materials, means either calcium oxide or calcium and magnesium oxides. The association has also adopted as official the "interpretation of the word lime as applied to fertilizer" as follows:

"The term 'lime' shall not be used in the registration, labeling, or guaranteeing of fertilizers or fertilizer materials, unless the lime is in a form to neutralize soil acidity, such as the oxide, hydroxide, or carbonate, or equivalent magnesia compounds."

Lime-oxide equivalent.—The proportion of oxide of lime in a carbonate or hydroxide. In pure material the ratio is approximately 2 parts of oxide (burned lime) to 3 parts of hydroxide (slaked lime) or 4 parts of carbonate.

Lime requirement.—The quantity of lime necessary to add to a soil to produce a slight alkaline reaction. It is usually stated in pounds of lime per acre to the depth of 6 inches or more.

Land plaster.—Gypsum, or sulfate of lime. It supplies calcium to the soil but has no neutralizing effect.

Magnesian or dolomitic lime.—Lime made from a limestone that contains from 10 to 15 percent or more of magnesium carbonate.

Marble.—A very pure form of crystallized limestone.

Marl.—A form of carbonate of lime that has been deposited under water in nature. The term is used rather loosely to describe earthy or soft rock deposits rich in carbonate of lime.

Non-acid-forming fertilizer.—A fertilizer that is not capable of increasing the residual acidity of the soil.

Organic matter.—Animal or vegetable material that has been left in or added to a soil. It includes material in all stages of decomposition, from comparatively fresh material, the origin of which can be determined, to that in an advanced state of decomposition and in part, at least, combined with the mineral constituents of the soil.

Oxide of lime.—Oxide of lime, or quicklime, is formed from carbonate by burning, whereby the carbonic acid is driven off. It does not occur in nature. It is known in trade as burned lime, lump lime, quicklime, stone lime, caustic lime, or builder's lime.

pH.—"The pH value" is the most common term now used to express the degree of acidity or alkalinity. It is simply a number denoting the acidity of alkalinity of any solution, soil, or compound. A neutral soil has a pH value of 7; values above 7 denote alkalinity; values below 7 denote acidity.

Pulverized limestone.—Pulverized limestone (fine-ground limestone) is the product obtained by grinding either high-calcium or dolomitic limestone so that all of the material will pass a 20-mesh sieve and at least 75 percent will pass a 100-mesh sieve.

Reaction.—The term "reaction" is applied to the behavior of a solution or a solid, when moist, when brought in contact with certain dyes called indicators. A solution or solid (when moist) that turns blue litmus red is said to have an acid reaction and one that turns red litmus blue an alkaline reaction. Slaked lime or lime hydroxide has an alkaline reaction.

Slag.—A waste product from blast furnaces. Some basic slag contains phosphorus. Other slag, containing no phosphorus, may still contain lime sufficient to make it useful for agricultural purposes.

Sieves.—In grading ground or pulverized limestone or similar products, sieves of different-sized mesh or openings are used to separate the material into proportions of different grades of fineness. A 10-mesh sieve has 10 meshes to the running inch, or 100 meshes per square inch. A 60-mesh sieve has 3,600 meshes to the square inch.

Soil amendment.—A material added to the soil to improve its physical condition.

Waste lime.—Waste, or byproduct, lime is any industrial waste or byproduct from such sources as paper mills, tanneries, beet-sugar mills, acetylene plants, etc., that contains lime or lime and magnesia in forms that will neutralize acids. These materials frequently are high enough in lime to be used for agricultural purposes.

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